# A MULTI-WAVELENGTH MINI LIDAR FOR MEASUREMENTS OF MARINE BOUNDARY LAYER AEROSOL AND WATER VAPOR FIELDS


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## LONG-TERM GOAL

Our goals are to calibrate a multi-wavelength scanning lidar system and use it to characterize the aerosol and water vapor fields in the coastal marine boundary layer. Once representative data on this boundary layer are collected, we will use these data to develop models of the aerosol fields.

## SCIENTIFIC OBJECTIVES

Our scientific objectives are to improve models of the aerosol optical properties in the coastal marine boundary layer (MBL). Although various aerosol models exist, most of these are for the open ocean and few if any models can describe the boundary layer's aerosol optical properties where breaking waves and complex atmospheric dynamics exist. We plan to develop models of the vertical aerosol structure in the 15 m of the atmosphere directly above the ocean surface. In order to develop models of this type, measurements are needed which can map out the aerosol optical properties over space and time as a function of wave heights and meteorological conditions.

## APPROACH

Our approach was to use a scanning multi-wavelength lidar to measure the 4-D (space and time) aerosol optical fields. These measurements were carried out at Makai Research Pier on Oahu in order to characterize the aerosol properties in a marine setting. Measurements were made under various wave and wind conditions in order to obtain broad and representative data sets. We are collecting these data in order to test existing Navy aerosol models for the coastal environment. We have found that lidar calibration is a very important issue and we are making a concerted effort in this area by employing a number of independent but related tests. Such tests should characterize the lidar's calibration and the aerosol phase function at 180 degrees, both of which are required to correctly derive the aerosol scattering coefficient.

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## WORK COMPLETED

Currently, we are using a multi-wavelength lidar with a 12" scanner to measure four-dimensional aerosol optical properties. This system was developed with joint ONR/UH funding. The lidar source is a high power Nd:YAG laser system (Continuum Powerlite Model 9020) capable of radiating collinear laser beams of 8 nanosecond pulses at 1064 nm ( $\leq$ 1.6 J), 532 nm, 355 nm and 266 nm. A MIRAGE 800 tunable Ti-sapphire laser system can provide tunable pulses from 710-910 nm (100 mJ at 800 nm) when pumped with 450 mJ of 532 nm beam from the frequency doubled Nd:YAG laser. Although we are currently not employing this latter capability, it will eventually be used for detection of water vapor fields using the DIAL technique.

In order to account for fluctuations in laser pulse intensity, an integrating sphere is used to couple a small fraction of the laser light at each wavelength to fast photo-diodes. The diode signals are digitized and used to calculate the pulse energies, which normalize the final results. A retractable DFM scanner is used to direct the outgoing laser beam. Opaque light tubes have been used to shield the laser beam from the detection optics. We found that such shielding dramatically reduced the amplitude of the initial pulse on the detectors, virtually eliminating initial saturation.

The light backscattered by the aerosol is reflected back into an 28 cm Schmidt-Cassegrain telescope. The 532 nm backscattered radiation is detected by a gated Thorn/EMI 9863 photomutiplier tube (PMT). After low-pass filtering, the PMT analog signal is digitized at 60 Mhz using a PC-mounted Gage 6012 12 bit ADC. The 1064 nm radiation is collected using an EG&G C30954 Si Avalanche Photo Diode (APD). The APD signal is digitized using a second 12-bit ADC. The controlling software package is a Windows application written in 16-bit C. We have designed and constructed a multi-wavelength receiver package that will allow us to measure both near and far field backscatter in separate channels at four wavelengths. We also plan to use single channel $N_2$ Raman signals to provide calibrated signals at wavelengths of 424.3 and 608.4 nm (shifted from the 355 and 532 nm laser lines, respectively). These Raman signals are weaker than the Mie-Rayleigh signals, and therefore we are building a 60 cm telescope receiver. Our present the lidar facility is now

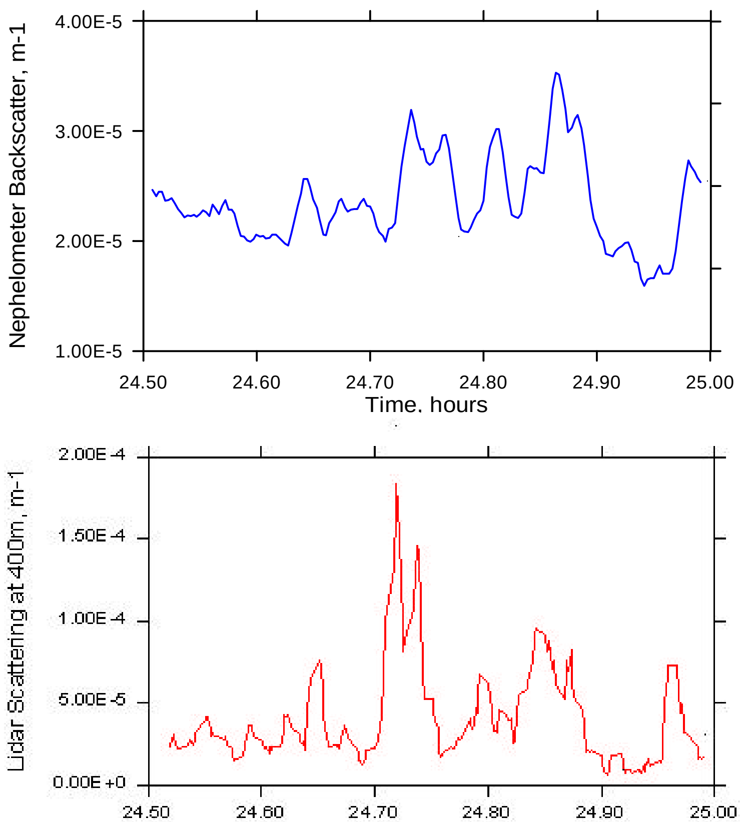


**Figure 1**: Nephelometer (blue) & Lidar (red) data

fully operational at 532 and 1064 nm. It is located at Makapu'u (Makai Research Pier), on the south-east side of the island of O'ahu, and we are routinely collecting data.

**RESULTS**

Approximately 1 km offshore from the Makai Research Pier, there are two small islands. Waves break on either side of these islands and the salt spray is carried towards the shore. Depending on the direction in which the wind is blowing, these salt plumes can be carried towards the lidar site. Figure 1 shows an example where these salt plumes were detected simultaneously by both the lidar (532 nm) and the aerosol nephelometers run by Dr. Antony Clarke and co-workers. Although there is an offset of about 100 seconds between the two data sets (corresponding to the measured wind speed of ~4 m/sec), similar variations in light scattering are clearly seen by both instruments. Figure 2 shows how the aerosol plumes travel towards the lidar with time. These measurements were made at 4 second intervals, pointing the laser beam up wind. Due to variations in wind direction we do not expect that the salt plumes will always remain in the beam. This horizontal variability is illustrated in Fig. 3 which shows a two dimensional horizontal plot of the aerosol scattering at 532 nm and ~5 m height from the sea surface. Salt plumes can be seen coming from the breaking waves off the Manana and Kaahikaipu islands. This measurement was made by scanning the lidar beam at a rate of 1 degree per sec. and each beam is the average of ten laser shots (0.5 sec.). We have now collected over 100 of these horizontal, as well as vertical, 2-D distributions of aerosol fields as a function of wind speed and direction at 532 nm. We have also started similar measurements at 1064 nm.

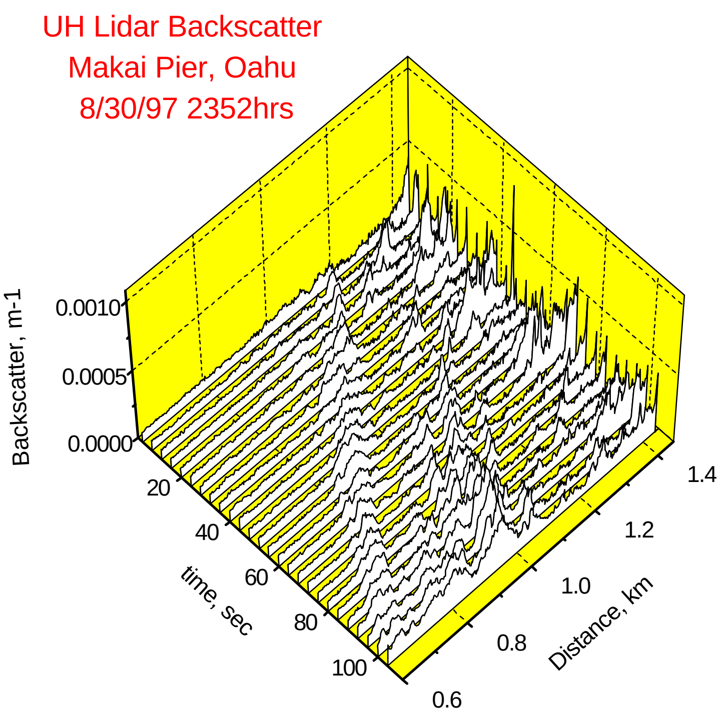


**Figure 2**: Backscatter profiles versus time

In order to derive aerosol scattering coefficients from lidar measurements, we require the lidar calibration factor (determined by the laser pulse power and the receiver efficiency) and the aerosol phase function at 180 degrees scattering angle. In order to determine the aerosol phase function we have employed Mie calculations from aerosol size distributions for existing marine aerosol model of Porter and Clarke. The lidar calibration was then empirically adjusted so that the aerosol

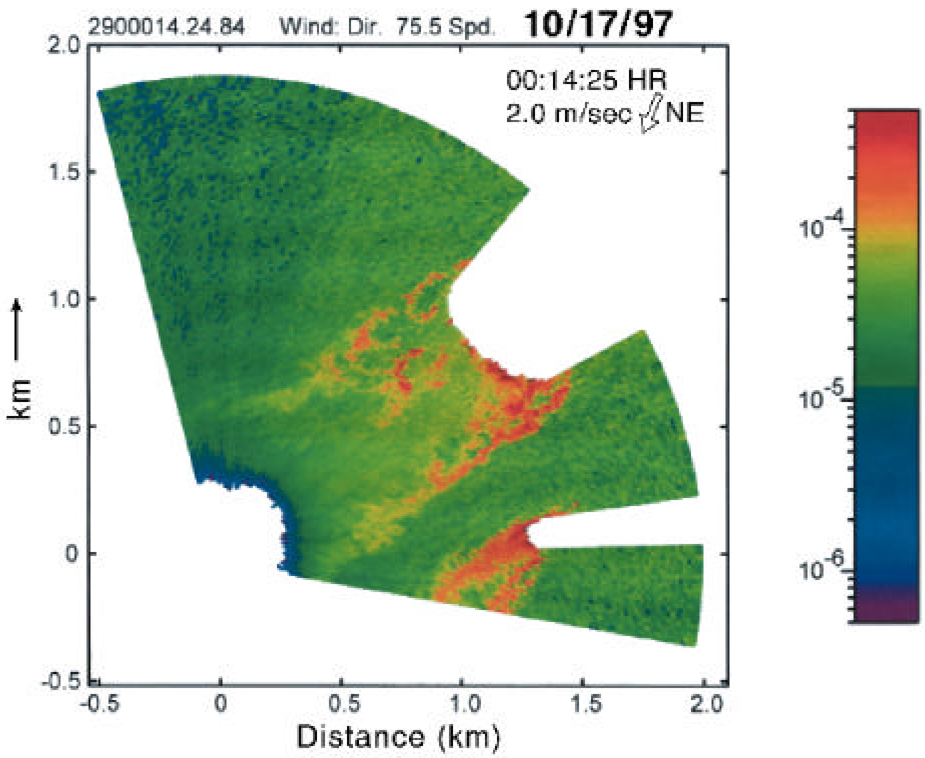


**Figure 3**: 2-D lidar backscatter

scattering coefficients derived from the lidar agreed with those measured with a nephelometer positioned on the Pier. Experience has shown that in a marine environment the lidar scanner mirrors tend to get coated with sea-salt, reducing the receiver efficiency. Under these conditions, frequent calibration is required. One test of our calibration ability is to aim the lidar horizontally into the wind and average the lidar measurements. If the aerosol concentration is homogeneous with distance then the scattering coefficient derived from the lidar should not change with distance as suggested by Reagan. Such an approach was used in deriving the results shown in Fig. 3. Although this preliminary calibration effort gave reasonable results, further validation and improvements are necessary.

**IMPACT/APPLICATION**

We have used a multi-wavelength scanning lidar to measure the three dimensional distribution of aerosol fields in the coastal marine boundary layer. These measurements clearly show that the aerosol fields are heterogeneous and are affected by breaking waves and wind conditions. These data sets will be invaluable in the testing and developing models of the aerosol optical properties of the coastal lower marine boundary layer. Simultaneous in situ measurements will provide calibration of the lidar system.

**TRANSITIONS**

Our lidar measurements are linked to two ONR projects. The proposal “Physicochemical and Optical Characterization of Boundary Layer Aerosol Fields” (PI: Antony Clarke) will provide data which can help to calibrate our lidar measurements. The proposal “Aerosol Size Distribution ” (PI: Kusiel Shifrin at OSU) will use our multi-wavelength measurements to derive aerosol size distributions.

## RELATED PROJECTS

1) We (PI: Shiv Sharma) are currently begining the development of a water vapor DIAL lidar system "Center for the study of water vapor fields and their radiative effects over Hawaii". This project is funded by NASA and will be dovetailed together with our existing ONR lidar system. This enhanced capability will improve the utility of the ONR lidar to provide rapid measurements of water vapor in the atmosphere.

2) We (PI: John Porter) are currently funded by NASA, in two separate efforts, to test satellite derived products from the SeaWifs and various EOS-AM satellite sensors. This is part of the SIMBIOS effort and the EOS-AM validation effort. The lidar measurements will occasionally be used for these efforts.

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